C&EE 141

Gravity Loads, Load Factors and Load Combinations

AISC Design Provisions

Overview

Design Provisions

- Allowable Strength Design (ASD)
  - Legacy approach to design
  - Applied loads are not factored up
  - Strength of steel material is reduced by a factor of safety to restrict required strength to allowable levels
- Load and Resistance Factor Design (LRFD)
  - Applied loads are factored up
  - Capacity of steel material is reduced by a reduction factor

Nominal Capacity is Common

- ASD:
  - Required Strength at Unfactored Load Combinations = R_a
  - Allowable Strength= R_n/Ω
- LRFD
  - Required Strength at Factored Load Combinations = R_u
  - Design Strength = ϕR_n

ALWAYS WORKING FROM SAME NOMINAL CAPACITY!

Structural Safety

Structural members must always be designed to carry some reserve capacity to account for overload and under strength, due to:

- Dimensional tolerances
  - Fabrication
  - Construction
- Material strength variations
- Limits of simplified design equations
- Uncertainty in applied loads

Probability Distribution of Load and Resistance

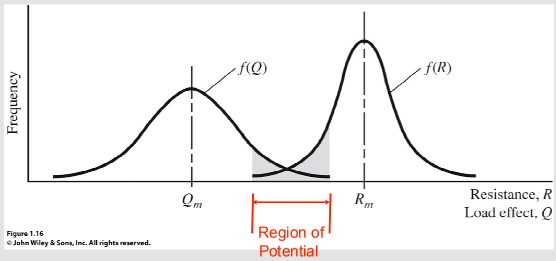

Figure 1.16
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Reliability of WF Beam with Uniform Moment

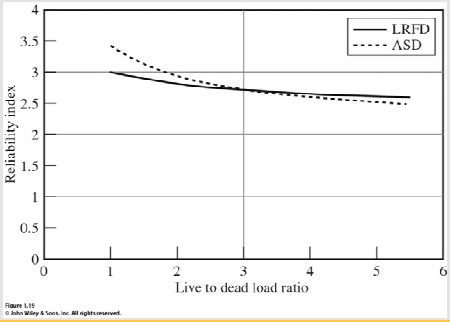

Figure 1.10
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Structural Safety

- The magnitude of a "factor of safety" (or "reliability index") is a function of economics versus probability of occurrence
- Zero probability of failure is uneconomical
- No margin of safety is illogical and ethically unacceptable

LRFD Load Combinations

- Load Combinations per AISC pg 2-10

Load and Resistance Factor Design

For LRFD, the required strength is determined from the following factored combinations,[1] which are based on ASCE/SEI 7 Section 2.3:

1. $1.4D$	(2-3a)
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$	(2-3b)
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (0.5L \text{ or } 0.5W)$	(2-3c)
4. $1.2D + 1.0W + 0.5L + 0.5(L_r \text{ or } S \text{ or } R)$	(2-3d)
5. $1.2D + 1.0E + 0.5L + 0.2S$	(2-3e)
6. $0.9D + 1.0W$	(2-3f)
7. $0.9D + 1.0E$	(2-3g)

ASD Load Combinations

- Load Combinations per AISC pg 2-11

Allowable Strength Design

For ASD, the required strength is determined from the following combinations, which are also based on ASCE/SEI 7 Section 2.4:

1.	D	(2-4a)
2.	$D + L$	(2-4b)
3.	$D + (L_r$ or S or $R)$	(2-4c)
4.	$D + 0.75L + 0.75(L_r$ or S or $R)$	(2-4d)
5.	$D + (0.6W$ or $0.7E)$	(2-4e)
6a.	$D + 0.75L + 0.75(0.6W) + 0.75(L_r$ or S or $R)$	(2-4f)
6b.	$D + 0.75L + 0.75(0.7E) + 0.75S$	(2-4g)
7.	$0.6D + 0.6W$	(2-4h)
8.	$0.6D + 0.7E$	(2-4i)

Load Combinations

- Where:

D = dead load
L = live load due to occupancy
L_r = roof live load
S = snow load
R = nominal load due to initial rainwater or ice exclusive of the ponding contribution
W = wind load
E = earthquake load

LRFD Resistance Factors & ASD Safety Factors

- Per AISC pg 2-12

$\phi = 0.90$ for limit states involving yielding
$\phi = 0.75$ for limit states involving rupture

$\Omega = 1.67$ for limit states involving yielding
$\Omega = 2.00$ for limit states involving rupture

The general relationship between the safety factor, Ω, and the resistance factor, ϕ, is

$$\Omega = \frac{1.5}{\phi} \qquad (2\text{–}5)$$

LRFD Design

3. Design for Strength Using Load and Resistance Factor Design (LRFD)

Design according to the provisions for *load and resistance factor design* (LRFD) satisfies the requirements of this Specification when the *design strength* of each *structural component* equals or exceeds the *required strength* determined on the basis of the *LRFD load combinations*. All provisions of this Specification, except for those in Section B3.4, shall apply.

Design shall be performed in accordance with Equation B3-1:

$$R_u \le \phi R_n \qquad \text{(B3-1)}$$

where

R_u = required strength using LRFD load combinations
R_n = *nominal strength*, specified in Chapters B through K
ϕ = *resistance factor*, specified in Chapters B through K
ϕR_n = design strength

Spec: B3.3

ASD Design

4. Design for Strength Using Allowable Strength Design (ASD)

Design according to the provisions for *allowable strength design (ASD)* satisfies the requirements of this Specification when the *allowable strength* of each *structural component* equals or exceeds the *required strength* determined on the basis of the *ASD load combinations*. All provisions of this Specification, except those of Section B3.3, shall apply.

Design shall be performed in accordance with Equation B3-2:

$$R_a \le R_n/\Omega \qquad \text{(B3-2)}$$

where

R_a = required strength using ASD load combinations
R_n = *nominal strength*, specified in Chapters B through K
Ω = *safety factor*, specified in Chapters B through K
R_n/Ω = allowable strength

Spec: B3.4

Serviceability

- In addition to having strength for the imposed loads, the structure must consider *serviceability*

L1. GENERAL PROVISIONS

Serviceability is a state in which the function of a building, its appearance, maintainability, durability and comfort of its occupants are preserved under normal usage. Limiting values of structural behavior for serviceability (such as maximum deflections and accelerations) shall be chosen with due regard to the intended function of the structure. Serviceability shall be evaluated using appropriate *load combinations* for the *serviceability limit states* identified.

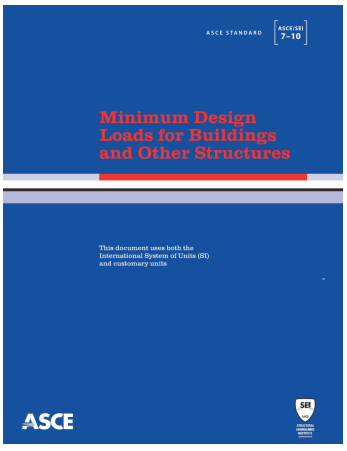
Spec: L1

Serviceability

- Serviceability limit states include:
  - Deflection
  - Vibration
  - Wind-Induced Motion
  - Thermal Expansion/Contraction
  - Connection Slip

ASCE 7-10

Dead & Live Loads



ASCE 7-10

2.2 SYMBOLS AND NOTATION

D = dead load
D_i = weight of ice
E = earthquake load
F = load due to fluids with well-defined pressures and maximum heights
F_a = flood load
H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
L = live load
L_r = roof live load
R = rain load
S = snow load
T = self-straining force
W = wind load
W_i = wind-on-ice determined in accordance with Chapter 10

Dead Loads

- The self weight of the structure + all permanently attached equipment and fixtures.
  - Examples of the self weight of the structure: concrete fill on metal deck, steel beams, steel girders, connection plates and bolts, miscellaneous framing for lateral bracing, etc.
  - Examples of permanently attached equipment and fixtures: pipes, electrical conduit, air conditioning and heating units, ducts, light fixtures, floor and roof coverings, ceilings, building exteriors, etc.
- Dead loads act continuously while the structure is in service.
- Dead loads are known accurately, but not until design is done (iterative procedure)

ASCE 7-10: Dead Loads

3.1 DEAD LOADS

3.1.1 Definition. Dead loads consist of the weight of all materials of construction incorporated into the building including, but not limited to, walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding, and other similarly incorporated architectural and structural items, and fixed service equipment including the weight of cranes.

3.1.2 Weights of Materials and Constructions. In determining dead loads for purposes of design, the actual weights of materials and constructions shall be used provided that in the absence of definite information, values approved by the authority having jurisdiction shall be used.

3.1.3 Weight of Fixed Service Equipment. In determining dead loads for purposes of design, the weight of fixed service equipment, such as plumbing stacks and risers, electrical feeders, and heating, ventilating, and air conditioning systems shall be included.

Sample Dead Loads

ITEM	WEIGHT
Light Weight Concrete Fill on Metal Deck (3" Deck + 3 ¼" Topping)	47 psf
Insulating Fill on Metal Deck	20 psf
Steel Plate	490 pcf
Carpeting or Linoleum Flooring	0.5 psf
Tile Flooring	2 psf
Mechanical Systems (Office Building)	5 psf
Mechanical Systems (Central Plant)	15 psf
Ceilings: Hard Lid	8 psf
Ceilings: T-bar	2 psf
Lights	1 psf
Roofing	10 psf
Soil	110 pcf
Concrete Toppings and Equipment Pads	150 pcf

Live Loads

- Gravity loads acting while structure is in service.
- Vary in magnitude and location.
- Examples of live loads: human occupants, furniture, moveable equipment, vehicles, stored goods.
- The determination of appropriate live loads is a function of the use of the area and of the probability of occurrence.
- Generally, live loads are prescribed by Building Codes.

Live Load Variation Over Time

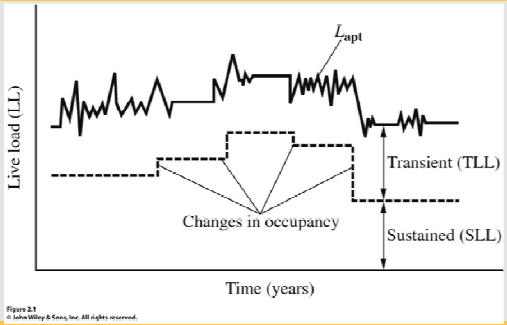


Figure 2.1
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ASCE 7-10: Live Loads

LIVE LOAD: A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads, such as wind load, snow load, rain load, earthquake load, flood load, or dead load.

ROOF LIVE LOAD: A load on a roof produced (1) during maintenance by workers, equipment, and materials and (2) during the life of the structure by movable objects, such as planters or other similar small decorative appurtenances that are not occupancy related.

ASCE 7-10 4.1

ASCE 7-10: Live Loads

4.3 UNIFORMLY DISTRIBUTED LIVE LOADS

4.3.1 Required Live Loads

The live loads used in the design of buildings and other structures shall be the maximum loads expected by the intended use or occupancy, but shall in no case be less than the minimum uniformly distributed unit loads required by Table 4-1, including any permissible reduction.

4.3.2 Provision for Partitions

In office buildings or other buildings where partitions will be erected or rearranged, provision for partition weight shall be made, whether or not partitions are shown on the plans. Partition load shall not be less than 15 psf (0.72 kN/m^2).

EXCEPTION: A partition live load is not required where the minimum specified live load exceeds 80 psf (3.83 kN/m^2).

Table 4-1 Minimum Uniformly Distributed Live Loads, L_o, and Minimum Concentrated Live Loads

Occupancy or Use	Uniform psf (kN/m^2)	Conc. lb (kN)
Apartments (see Residential)		
Access floor systems		
Office use	50 (2.4)	2,000 (8.9)
Computer use	100 (4.79)	2,000 (8.9)
Armories and drill rooms	150 (7.18)[e]	
Assembly areas and theaters		
Fixed seats (fastened to floor)	60 (2.87)[e]	
Lobbies	100 (4.79)[e]	
Movable seats	100 (4.79)[e]	
Platforms (assembly)	100 (4.79)[e]	
Stage floors	150 (7.18)[e]	
Balconies and decks	1.5 times the live load for the occupancy served. Not required to exceed 100 psf (4.79 kN/m^2)	
Catwalks for maintenance access	40 (1.92)	300 (1.33)
Corridors		
First floor	100 (4.79)	
Other floors, same as occupancy served except as indicated		
Dining rooms and restaurants	100 (4.79)[e]	
Dwellings (see Residential)		
Elevator machine room grating (on area of 2 in. by 2 in. (50 mm by 50 mm))		300 (1.33)
Finish light floor plate construction (on area of 1 in. by 1 in. (25 mm by 25 mm))		200 (0.89)
Fire escapes	100 (4.79)	
On single-family dwellings only	40 (1.92)	
Fixed ladders	See Section 4.5	

Residential		
One- and two-family dwellings		
Uninhabitable attics without storage	10 (0.48)[i]	
Uninhabitable attics with storage	20 (0.96)[i]	
Habitable attics and sleeping areas	30 (1.44)	
All other areas except stairs	40 (1.92)	
All other residential occupancies		
Private rooms and corridors serving them	40 (1.92)	
Public rooms[e] and corridors serving them	100 (4.79)	
Roofs		
Ordinary flat, pitched, and curved roofs	20 (0.96)[v]	
Roofs used for roof gardens	100 (4.79)	
Roofs used for assembly purposes	Same as occupancy served	
Roofs used for other occupancies	"	"
Awnings and canopies		
Fabric construction supported by a skeleton structure	5 (0.24) nonreducible	300 (1.33) applied to skeleton structure
Screen enclosure support frame	5 (0.24) nonreducible and applied to the roof frame members only, not the screen	200 (0.89) applied to supporting roof frame members only
All other construction	20 (0.96)	
Primary roof members, exposed to a work floor		
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages		2,000 (8.9)
All other primary roof members		300 (1.33)
All roof surfaces subject to maintenance workers		300 (1.33)
Schools		
Classrooms	40 (1.92)	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
First-floor corridors	100 (4.79)	1,000 (4.45)
Scuttles, skylight ribs, and accessible ceilings		200 (0.89)
Sidewalks, vehicular driveways, and yards subject to trucking	250 (11.97)[v,p]	8,000 (35.60)[v]
Stairs and exit ways	100 (4.79)	300[r]
One- and two-family dwellings only	40 (1.92)	300[r]

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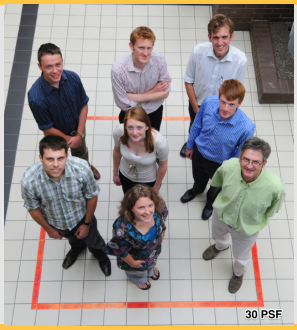
Live Loads

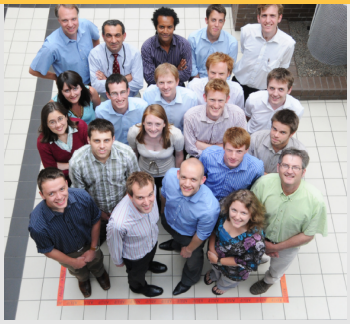


Attic Space

Live Loads

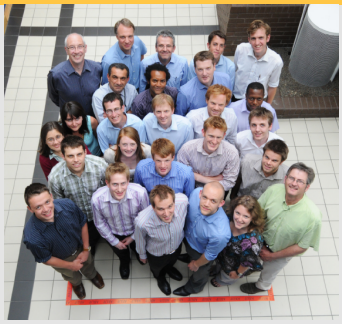
Theater Seats

Live Loads



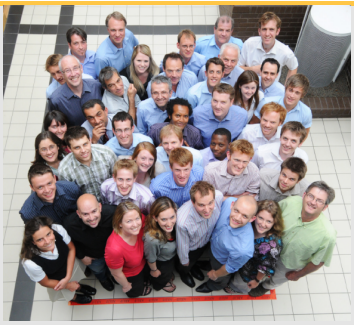
80 psf - Exit Corridors

Live Loads



100 psf - Fire Escapes, Dining Areas, 1st Floor Corridors

Live Loads



150 psf - Armories

ASCE 7-10: Live Loads

4.3.3 Partial Loading

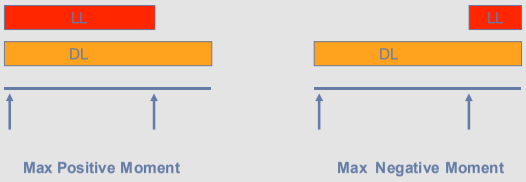
The full intensity of the appropriately reduced live load applied only to a portion of a structure or member shall be accounted for if it produces a more unfavorable load effect than the same intensity applied over the full structure or member. Roof live loads shall be distributed as specified in Table 4-1.

4.4 CONCENTRATED LIVE LOADS

Floors, roofs, and other similar surfaces shall be designed to support safely the uniformly distributed live loads prescribed in Section 4.3 or the concentrated load, in pounds or kilonewtons (kN), given in Table 4-1, whichever produces the greater load effects. Unless otherwise specified, the indicated concentration shall be assumed to be uniformly distributed over an area 2.5 ft (762 mm) by 2.5 ft (762 mm) and shall be located so as to produce the maximum load effects in the members.

Partial Loading

- Live Load Must Be Applied For Maximum Effect
- Known as "Skip Loading"



Live Load Reductions

- The probability of the full Live Load acting simultaneously on the entire support member of a structure decreases with the amount of area supported by the member
- Therefore, Live Load reductions are allowed per the Building Code

Tributary Areas

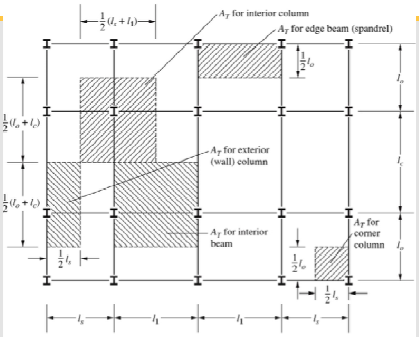


Figure 2.3
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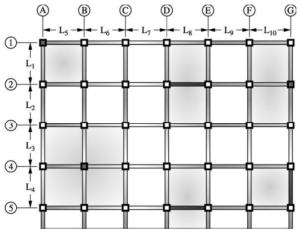
Influence Areas

- Influence areas are those areas that when loaded affect the design forces in a particular member of a structure.



$$A_I = K_{LL} A_T$$

where K_{LL} is the live load element factor depending on building geometry

Live Load Reductions

Table 4-2 Live Load Element Factor, K_{LL}

Element	K_{LL}[a]
Interior columns	4
Exterior columns without cantilever slabs	4
Edge columns with cantilever slabs	3
Corner columns with cantilever slabs	2
Edge beams without cantilever slabs	2
Interior beams	2
All other members not identified, including: Edge beams with cantilever slabs; Cantilever beams; One-way slabs; Two-way slabs; Members without provisions for continuous shear transfer normal to their span	1

[a]In lieu of the preceding values, K_{LL} is permitted to be calculated.

$K_{LL} A_T = A_I$, or the Influence Area

ASCE 7-10: Floor Live Load Reductions

4.7 REDUCTION IN LIVE LOADS

4.7.1 General

Except for roof uniform live loads, all other minimum uniformly distributed live loads, L_o in Table 4-1, shall be permitted to be reduced in accordance with the requirements of Sections 4.7.2 through 4.7.6.

4.7.2 Reduction in Uniform Live Loads

Subject to the limitations of Sections 4.7.3 through 4.7.6, members for which a value of $K_{LL}A_T$ is 400 ft^2 (37.16 m^2) or more are permitted to be designed for a reduced live load in accordance with the following formula:

$$L = L_o\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right) \qquad (4.7\text{-}1)$$

In SI:

$$L = L_o\left(0.25 + \frac{4.57}{\sqrt{K_{LL}A_T}}\right)$$

where

L = reduced design live load per ft^2 (m^2) of area supported by the member

L_o = unreduced design live load per ft^2 (m^2) of area supported by the member (see Table 4-1)

K_{LL} = live load element factor (see Table 4-2)

A_T = tributary area in ft^2 (m^2)

L shall not be less than $0.50L_o$ for members supporting one floor and L shall not be less than $0.40L_o$ for members supporting two or more floors.

ASCE 7-10: Floor Live Load Reductions

4.7.3 Heavy Live Loads

Live loads that exceed 100 lb/ft^2 (4.79 kN/m^2) shall not be reduced.

EXCEPTION: Live loads for members supporting two or more floors shall be permitted to be reduced by 20 percent.

4.7.4 Passenger Vehicle Garages

The live loads shall not be reduced in passenger vehicle garages.

EXCEPTION: Live loads for members supporting two or more floors shall be permitted to be reduced by 20 percent.

4.7.5 Assembly Uses

Live loads shall not be reduced in assembly uses.

4.7.6 Limitations on One-Way Slabs

The tributary area, A_T, for one-way slabs shall not exceed an area defined by the slab span times a width normal to the span of 1.5 times the slab span.

ASCE 7-10: Roof Live Load Reductions

4.8 REDUCTION IN ROOF LIVE LOADS

4.8.1 General

The minimum uniformly distributed roof live loads, L_o in Table 4-1, are permitted to be reduced in accordance with the requirements of Sections 4.8.2 and 4.8.3.

4.8.2 Flat, Pitched, and Curved Roofs

Ordinary flat, pitched, and curved roofs, and awning and canopies other than those of fabric construction supported by a skeleton structure, are permitted to be designed for a reduced roof live load, as specified in Eq. 4.8-1 or other controlling combinations of loads, as specified in Chapter 2, whichever produces the greater load effect. In structures such as greenhouses, where special scaffolding is used as a work surface for workers and materials during maintenance and repair operations, a lower roof load than specified in Eq. 4.8-1 shall not be used unless approved by the authority having jurisdiction. On such structures, the minimum roof live load shall be 12 psf (0.58 kN/m^2).

$$L_r = L_o R_1 R_2 \quad \text{where} \quad 12 \le L_r \le 20 \qquad (4.8\text{-}1)$$

where

L_r = reduced roof live load per ft^2 (m^2) of horizontal projection supported by the member

L_o = unreduced design roof live load per ft^2 (m^2) of horizontal projection supported by the member (see Table 4-1)

The reduction factors R_1 and R_2 shall be determined as follows:

$$R_1 = \begin{cases} 1 & \text{for } A_t \le 200 \text{ ft}^2 \\ 1.2 - 0.001A_t & \text{for } 200 \text{ ft}^2 < A_t < 600 \text{ ft}^2 \\ 0.6 & \text{for } A_t \ge 600 \text{ ft}^2 \end{cases}$$

where A_t = tributary area in ft^2 (m^2) supported by the member and

$$R_2 = \begin{cases} 1 & \text{for } F \le 4 \\ 1.2 - 0.05F & \text{for } 4 < F < 12 \\ 0.6 & \text{for } F \ge 12 \end{cases}$$

where, for a pitched roof, F = number of inches of rise per foot (in SI: $F = 0.12 \times$ slope, with slope expressed in percentage points) and, for an arch or dome, F = rise-to-span ratio multiplied by 32.

ASCE 7-10: LRFD Load Combinations

2.3 COMBINING FACTORED LOADS USING STRENGTH DESIGN

2.3.2 Basic Combinations

Structures, components, and foundations shall be designed so that their design strength equals or exceeds the effects of the factored loads in the following combinations:

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $1.2D + 1.0E + L + 0.2S$
6. $0.9D + 1.0W$
7. $0.9D + 1.0E$

- Note: "Strength Design" is a broad term that includes LRFD.

ASCE 7-10: LRFD Load Combinations

EXCEPTIONS:

1. The load factor on L in combinations 3, 4, and 5 is permitted to equal 0.5 for all occupancies in which L_o in Table 4-1 is less than or equal to 100 psf, with the exception of garages or areas occupied as places of public assembly.
2. In combinations 2, 4, and 5, the companion load S shall be taken as either the flat roof snow load (p_f) or the sloped roof snow load (p_s).

Where fluid loads F are present, they shall be included with the same load factor as dead load D in combinations 1 through 5 and 7.

Where load H are present, they shall be included as follows:

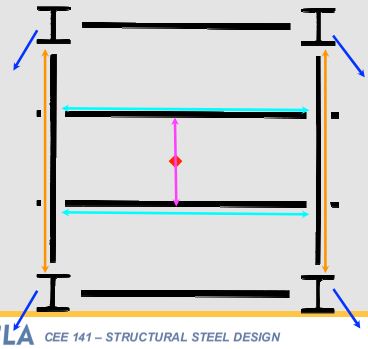
1. where the effect of H adds to the primary variable load effect, include H with a load factor of 1.6;
2. where the effect of H resists the primary variable load effect, include H with a load factor of 0.9 where the load is permanent or a load factor of 0 for all other conditions.

Effects of one or more loads not acting shall be investigated. The most unfavorable effects from both wind and earthquake loads shall be investigated, where appropriate, but they need not be considered to act simultaneously. Refer to Section 12.4 for specific definition of the earthquake load effect E.[1]

Each relevant strength limit state shall be investigated.

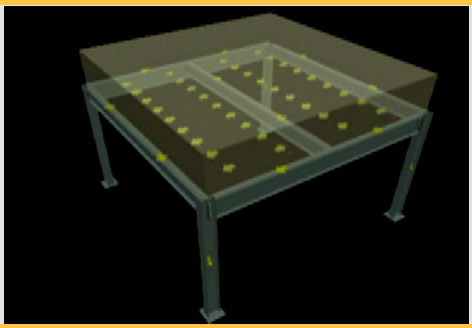
Determining Required Loads on Members

Load Path Concept

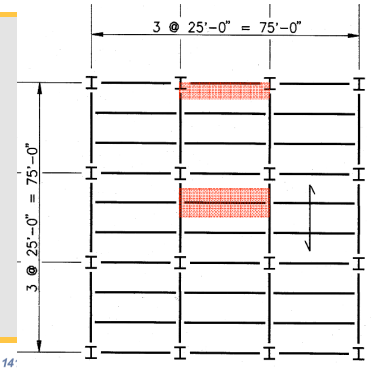


Load Path:
1. Load is applied to slab
2. Slab spans to beams
3. Beams span to girders
4. Girders span to columns
5. Columns supported by foundations

Load Path Concept



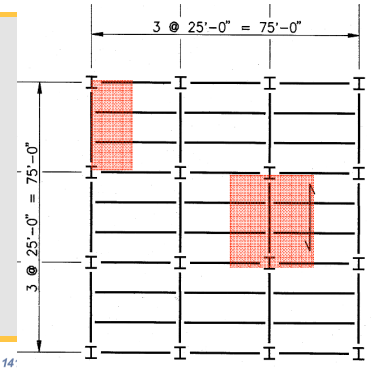
Load to Beams/Joists



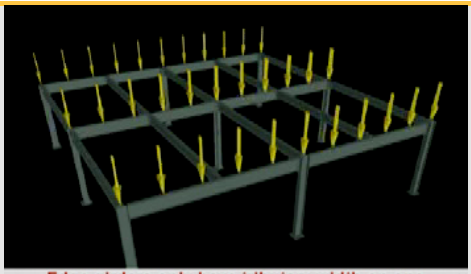
Load to Beams/Joists

Edge beams only have tributary width on one side, while interior beams have it on both sides.

Load to Girders

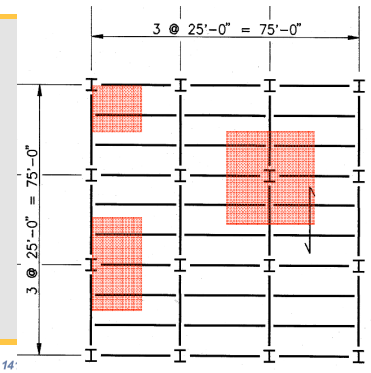


Load to Girders

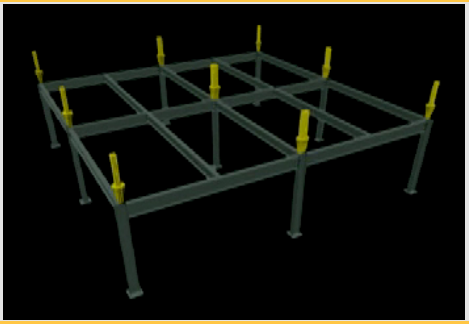


Edge girders only have tributary width on one side, while interior girders have it on both sides.

Load to Columns



Load to Columns



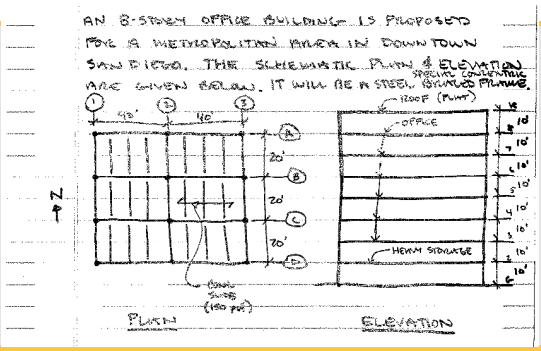
Dead & Live Load Tabulations

- Keeping track of the loads and the accumulation of load is extremely important
- A clear understanding of the Load Path is the key
- Keep it simple using a "bookkeeping" approach

Sample Problem

Dead & Live Load Tabulation

Sample Problem



Sample Problem

CONSTRUCTION INFORMATION:

1. 6" CONC. FLOOR SLABS & ROOF SLABS
2. 12" CONC. FLOOR SLABS AT HEAVY STORAGE
3. PARTITIONS = ~~20 psf~~ 15 psf
4. CEILINGS = 12 psf
5. MECHANICAL SYSTEMS = 5 psf
6. MISC LOADS = 3 psf
7. ROOFING = 10 psf

Problem:
Determine gravity loads on typical beams, girders and columns.